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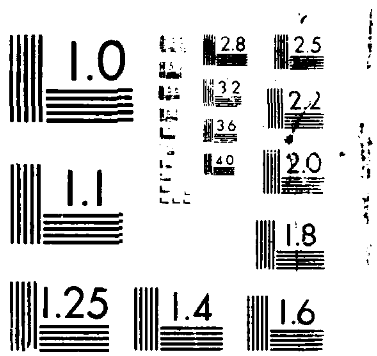

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A FIBER OPTIC COLLECTIVE FLIGHT CONTROL SYSTEM

FOR HELICOPTERS

A Short Thesis

by

ELLIS WAYNE GOLSON

Submitted to the College of Graduate Studies
Texas A&I University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 1988

Major Subject: Electrical Engineering

A FIBER OPTIC COLLECTIVE FLIGHT CONTROL SYSTEM

FOR HELICOPTERS

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ABSTRACT

A Fiber Optic Collective Flight Control System for Helicopters

May 1988

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United States Military Acadamy

Chairman of Advisory Committee:

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The objective of this thesis is to design a fiber optic transmission system to replace the present collective flight control system for helicopters. A discussion of the present collective control system is presented as well as fiber optic system components necessary to provide positive collective control of the aircraft. Computer simulation has been utilized where possible to verify modulation and receiver circuitry. The fiber optic system provides advantages in weight, surviveability, and cockpit organization.

DEDICATION

This thesis is dedicated to my wife, Rachel, whose patience and continual support are the primary motivating factors in my life.

ACKNOWLEDGEMENT

I wish to acknowledge the assistance of Mr. Homi Gorakhpurwalla, and Dr. John Linder in the preperation of this thesis. Their willingness to answer questions, knowledge, and enthusiasm for the subject of Electrical Engineering has provided me with an example to follow in the years to come.

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PRESENT COLLECTIVE FLIGHT CONTROL SYSTEM

The current method of controlling vertical flight in helicopters is a hydro-mechanical system using control tubes and hydraulic servos to effect pitch changes in the rotor blades. The collective control lever is located to the left of the pilots position and controls the vertical mode of flight.[1] A positive or upward motion on the collective control produces an increase in pitch on the rotor blades. Pitch is a term which refers to a change in the angle of attack of the rotor blade. The angle of attack is measured between the chord of the blade and the incoming relative wind. An increase in angle of attack produces more lift. A decrease in angle of attack produces less lift. The increase in pitch causes the aircraft to move upward or climb vertically. A negative or downward motion on the collective control produces a decrease in pitch on the rotor blades and a corresponding vertical descent of the aircraft. The pilots collective pitch control is connected to a system of push-pull tube assemblies and bell cranks. The push-pull tubes transfer the pilot input to the hydraulic cylinder valve. The bell cranks allow for the bending or change in direction of the push pull tubes in order to conform to the external design of the aircraft. The hydraulic cylinder valve controls the injection or venting of hydraulic fluid into the hydraulic servo. The hydraulic cylinder valve therefore controls the extension or compression of the hydraulic servo which is translated into an increase or decrease in pitch on the rotor blades by the collective lever. See figure (1).

The hydraulic system (on the AH-1 helicopter for example) is a close center, constant pressure, variable volume system. It produces 1500 plus or minus 25 pounds per square inch of pressure and has a maximum flow of 6.5 gallons per minute through the pump.[2] The pump is located on the transmission and is driven by a spline gear from the transmission. The total system consists of three sub systems. The two primary systems are intermixed through solenoid valves to provide hydraulic pressure to the flight controls in the event of failure of one system. The third system is electrically driven and is used with the weapon systems to boresight and to fly the aircraft in an emergency. As seen in figure (2), the pilot input from his collective control lever opens or closes the input valves located in the hydraulic cylinder. Since constant pressure is applied to the system, fluid flows into the cylinder at a constant rate when the valve is open. Correspondingly, the fluid flows out at a constant rate through the relief valve when a downward input is applied to the pilots collective control. The constant pressure system allows for smooth, consistent response to control inputs.

The range of motion of the pilots collective control lever is limited to less than 90 degrees. In the full down or zero pitch applied position, the rotor blades have a negligible angle of attack with the relative wind. Since there is no angle of attack there is no lift produced. As the pilot raises the collective control, the angle of attack of the rotor blades is increased to produce lift. When the angle of attack of the rotor blades is increased sufficiently, the lift produced by the rotor blades overcomes the weight of the helicopter and flight begins. The collective pitch control is so named because it changes the angle of attack of the rotor blades equally as they rotate. If only collective control inputs are made, the rotor blades would have the same pitch setting as they made their revolution around the helicopter. This is in contrast to the cyclic controls. The cyclic controls allow the pilot to adjust the helicopters position over the ground and the speed of the helicopter. The cyclic controls produce different angles of attack in the rotor blades depending on their position during the revolution. The two control inputs are intermixed in the rotor system by the swashplate.The swashplate is a rotating ring bearing mounted on a ball. The input from the cyclic control is made at one of three points on the swashplate. Since the swashplate is mounted on a ball, the cyclic inputs change the attitude of the swashplate much like that of a triangle mounted on a center support.

The major drawbacks to this system are its weight, survivability, and difficulty in adjustment. As shown in figure (1), the current collective control system has a minimum of three control tubes and two bell cranks with supports. The push-pull tubes are made of aluminum and the bell cranks of cast aluminum. Elimination or replacement of these components with a lighter material would be advantageous to the performance of the helicopter. The system is extremely difficult to adjust. Each push-pull tube must be an exact length in order to insure proper range of motion of the hydraulic servo. Survivability is limited in that a failure of a bolt connecting two tubes would result in loss of pitch control for the aircraft. A properly designed fiber optic system will correct these deficiencies as well as provide other inherent advantages.

1. Collective lever
2. Hydraulic cylinder assembly
3. Cylinder support
4. Hydraulic cylinder valve
5. Tube assembly
6. Droop compensator tube assembly
7. Bellcrank and support
8. Tube assembly
9. Bellcrank
10. Tube assembly
11. Cover
12. Boot
13. Pilot collective control stick
14. Down-lock strap
15. Tube assembly
16. Tube assembly
17. Boot
18. Gunner collective control stick

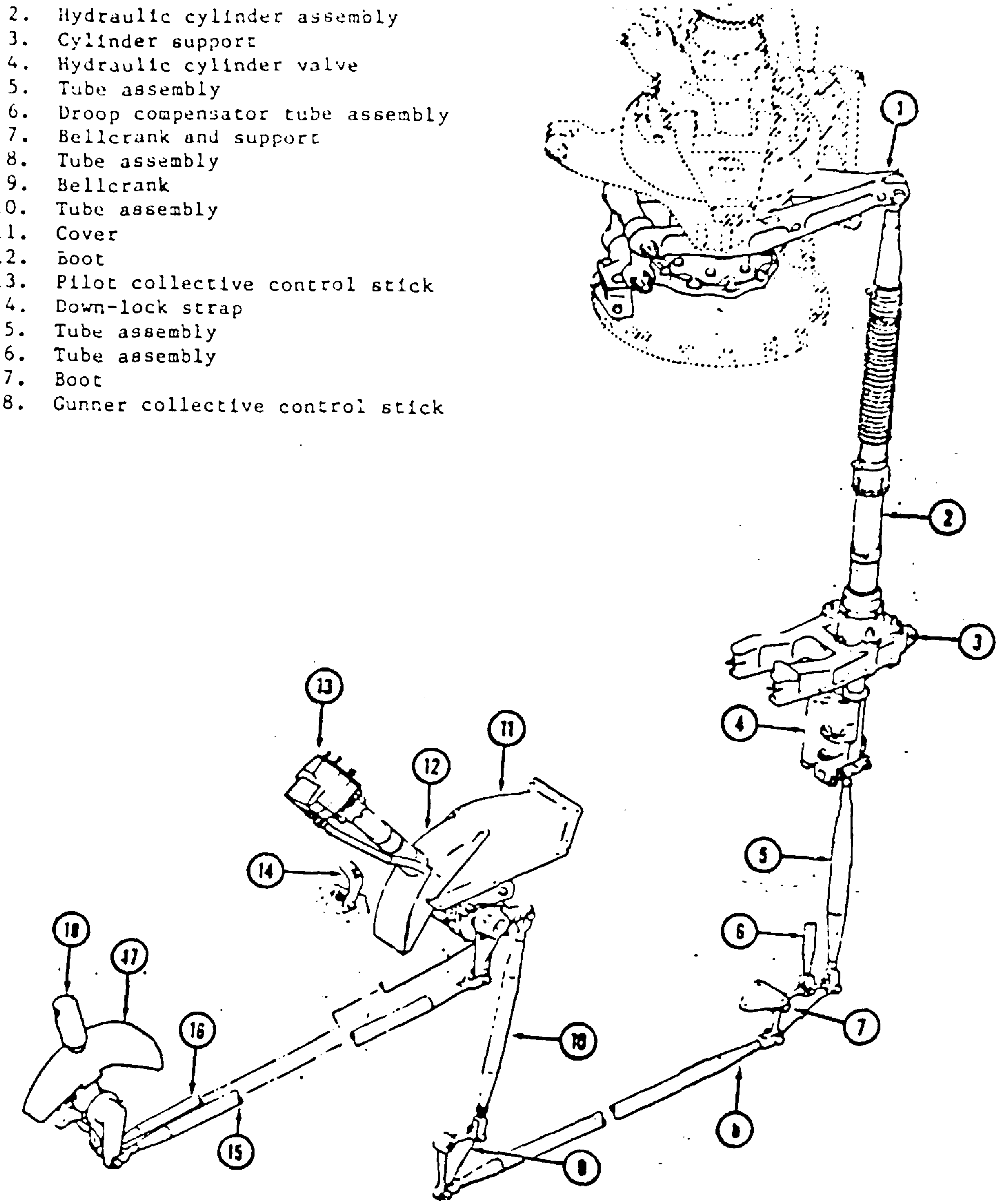

Figure (1) Present Collective Control System

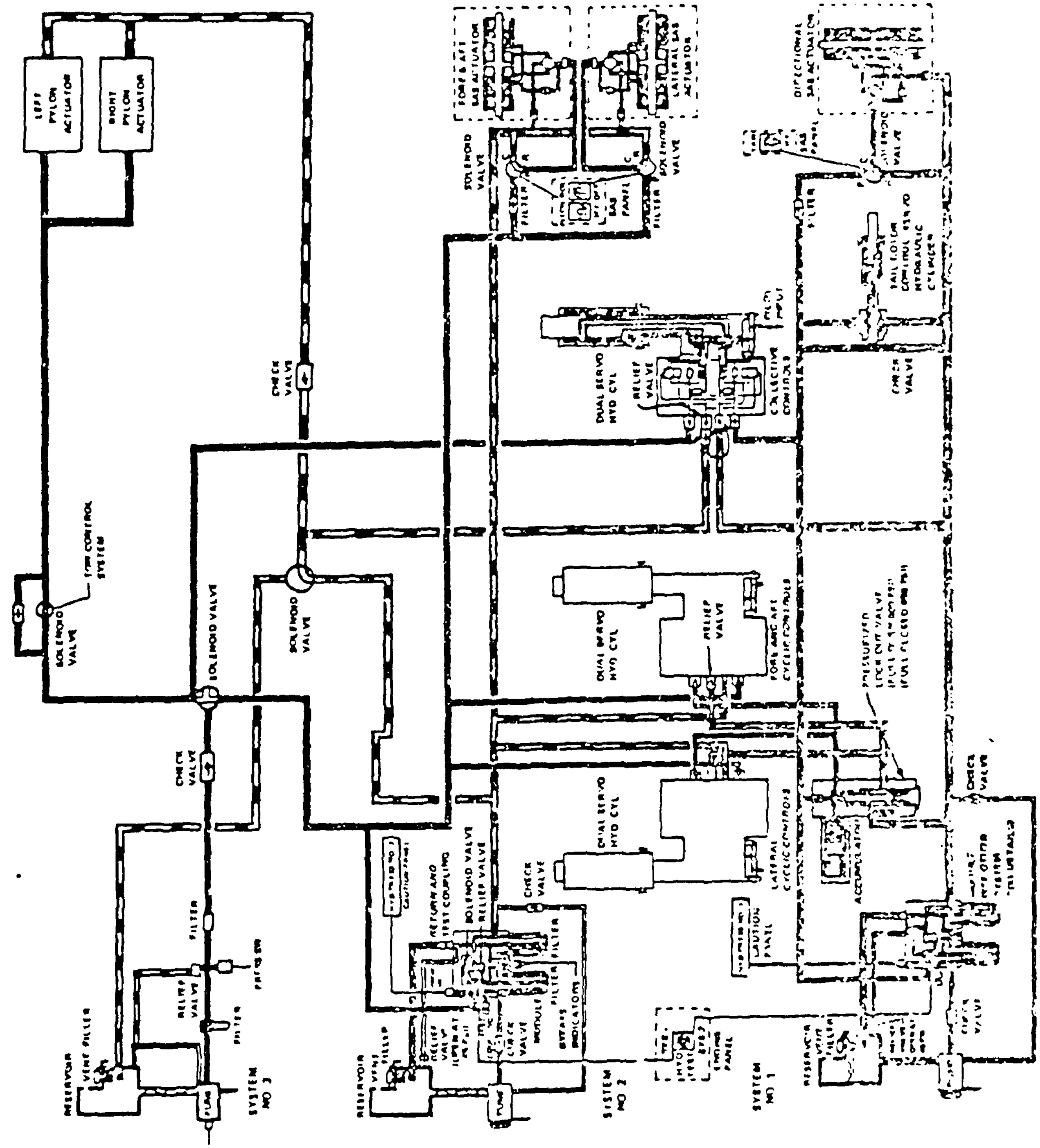

Figure (2) Hydraulic System Schematic

SENSORS

The first step in developing a fiber optic system to replace the current collective control system in helicopters is to develop a method of sensing the pilot's inputs into the system. In order to minimize the number of changes in flight techniques brought on by the replacement of the collective control system, the current collective control lever should be retained with as few modifications as possible. Therefore, a method should be found to interface the up and down motion of the collective control to the fiber optic system. A properly designed fiber optic displacement sensor will easily meet this need.

There are two basic categories of fiber optic sensors, intrinsic and reflective. In an intrinsic sensor the fibers ability to transmit light is determined by the environment in which it is placed. A reflective sensor measures the amount of light that is reflected from an object.[3] In the helicopter, the best method is to use an intrinsic displacement sensor. These sensors are simple in design and a direct correlation between the displacement of the collective control and the amount of light transmitted can be obtained. One such sensor that has been developed is the aperture intensity displacement sensor.[4] This sensor makes use of two light sources and a single optical transmission fiber. The light beamed from the sources is transported to fixed ports by optical fibers. The transmission fiber is connected to a sliding aperture that is centered between the apertures of the light sources. See figure (3). The light sources are set to emit light that is modulated to be 180 degrees out of phase with each other. Therefore, the modulation of the light transmitted with the sensing aperture centered essentially produces an unmodulated transmission of light. This transmission is interpreted by the receiver circuitry to be a reference point. If the sensing aperture moves up or down, the light transmitted is positively or negatively modulated. This modulation is sensed at the receiver as a positive or negative deviation from the reference point.

In the helicopter, sensing need only be done from a reference point up and then down back to the reference point. As noted in chapter I, the motion of the collective control is limited to less than 90 degrees. Therefore, a modification of the aperture intensity ratio system will work. A possible adaptation is to use one light source attached to a port with a facing optical transmission fiber across from the light source port. In between the light source port and the optical transmission fiber is placed a sliding partition that is solid on one end and has an aperture on the other end. This partition is connected to the collective control. With the collective control in the full down position, the solid end of the partition would be between the light source port and the optical transmission fiber. This setting would correspond to no pitch applied to the rotor system. As the collective control is raised, the partition moves so that the aperture becomes more and more aligned with the light source and the optical transmission fiber. This setting allows increasing amounts of light to be transmitted through the optical transmission fiber, which would result in increasing pitch applied to the rotor system. See fig (4). This sensor is most applicable to an analog control system.

The aperture intensity ratio sensor could be used in the helicopter if we modify slightly the collective control. The collective control would be changed to a spring loaded center position lever. When the pilot applied upward pressure on the lever, the sensor would transmit the upward displacement signal. When the proper pitch is attained the pilot would release pressure on the collective control and it would return to the center position. The same process would occur when a decrease in pitch was desired. This application has some advantages. The reduced range of motion of the collective control would enhance the control response of the aircraft. This application also would lend itself to a constant or hold setting on the pitch of the rotor blades with a minimum of logic circuitry at the receiver end. However, the demodulation circuitry necessary to sense a phase shift is quite complicated. This fact leads me to the final possibility for the fiber optic sensor.

Again we will modify the pilots collective control to be a center position lever. Using the two light source ports of the aperture intensity ratio displacement sensor, we place two fiber optic transmission lines across from them. See figure (5) Now each light source port has its own transmission line. The sliding partition is mounted between the light source ports and the transmission lines with its opening centered between the two light source ports. This arrangement produces no light in either transmission line. When the partition is moved upward, the opening aligns with the upper light source port signaling an up command through its facing transmission line. The same thing happens when the partition is moved downward. This arrangement uses an extra transmission line. However, the arrangement quickly adapts itself to pulse width modulation of the light signal. This attribute can be very advantageous in facilitating a hydraulic interface with the aircraft. The addition of the extra fiber adds little if any weight to the overall system. Therefore, due to it's ability to accurately sense the displacement of the collective control lever and the ability to reduce necessary logic circuits at the hydraulic interface, the two transmission fiber sensor is the choice for the fiber optic collective control system.

The two fiber displacement sensor will produce losses at the interface of the fibers. These losses are primarily due to the numerical aperture of the fiber defined in chapter V. Using a fiber with a numerical aperture of 0.1868 produced from an all silica core with a cladding of silica doped with 2% Florine, the losses would be approximately 14.5 dB at the interface. This loss could be reduced by the use of lens coupling. However, for the purposes of this paper, we will assume the worst case loss under these conditions.

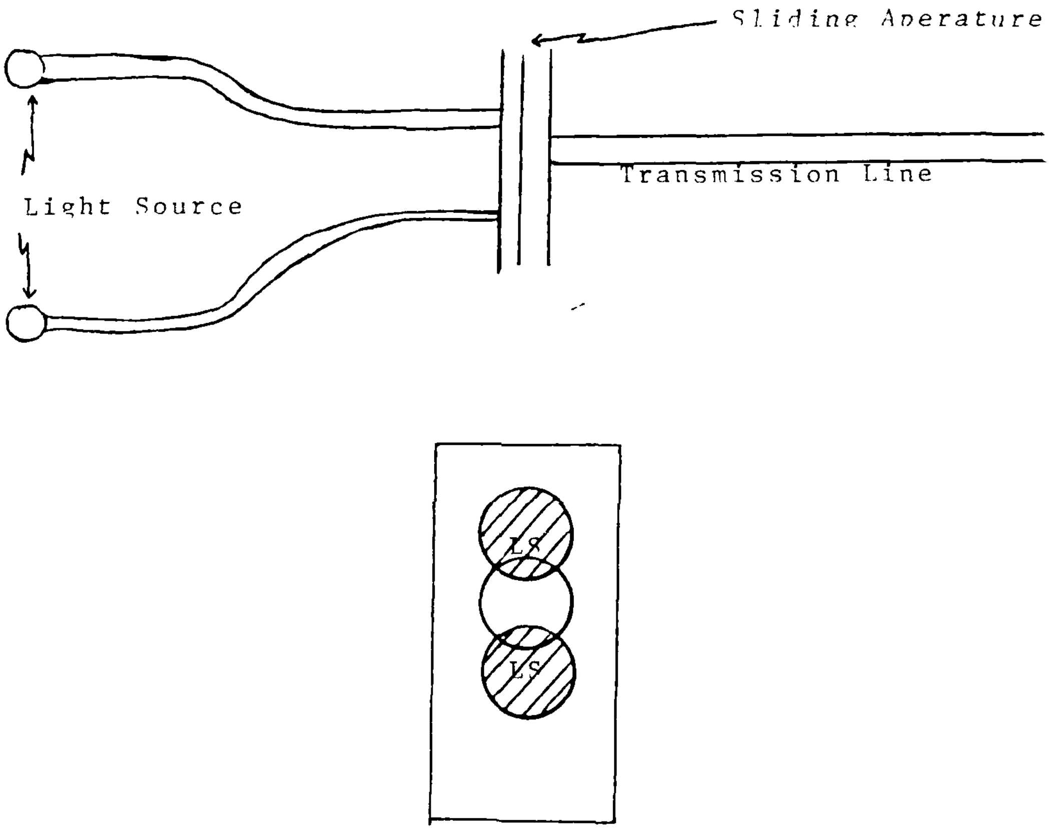

Figure (3) Aperature intensity ratio Sensor

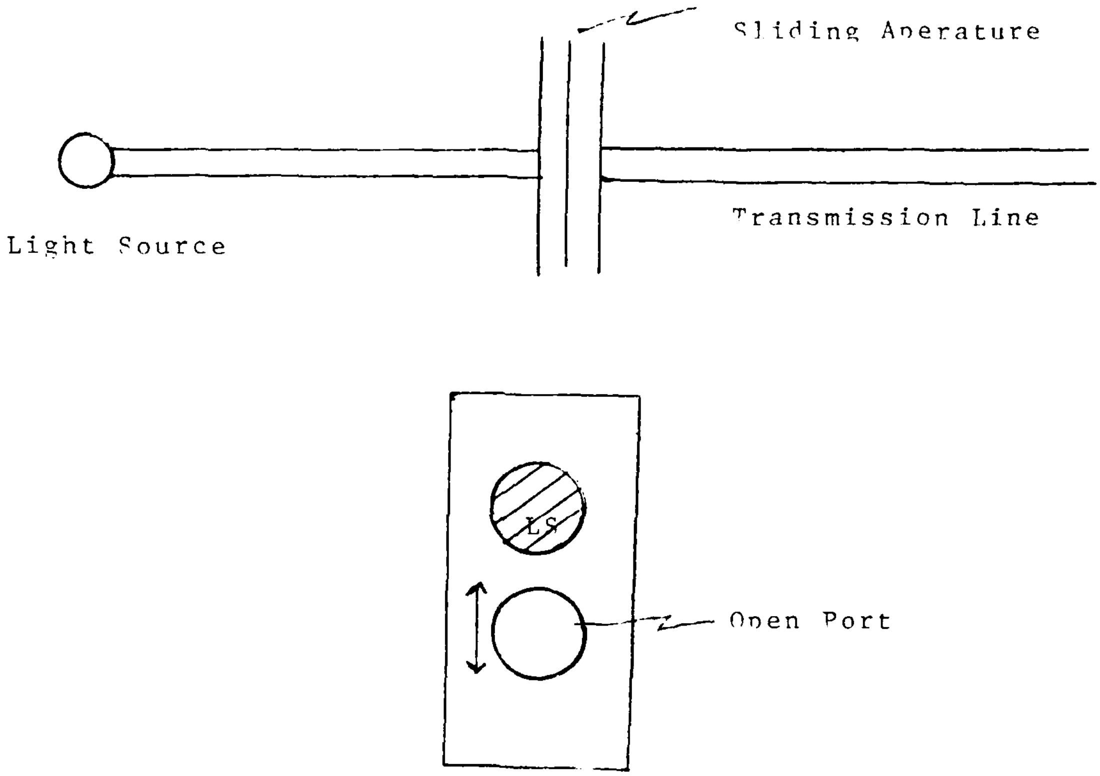

Figure (4) One port displacement sensor

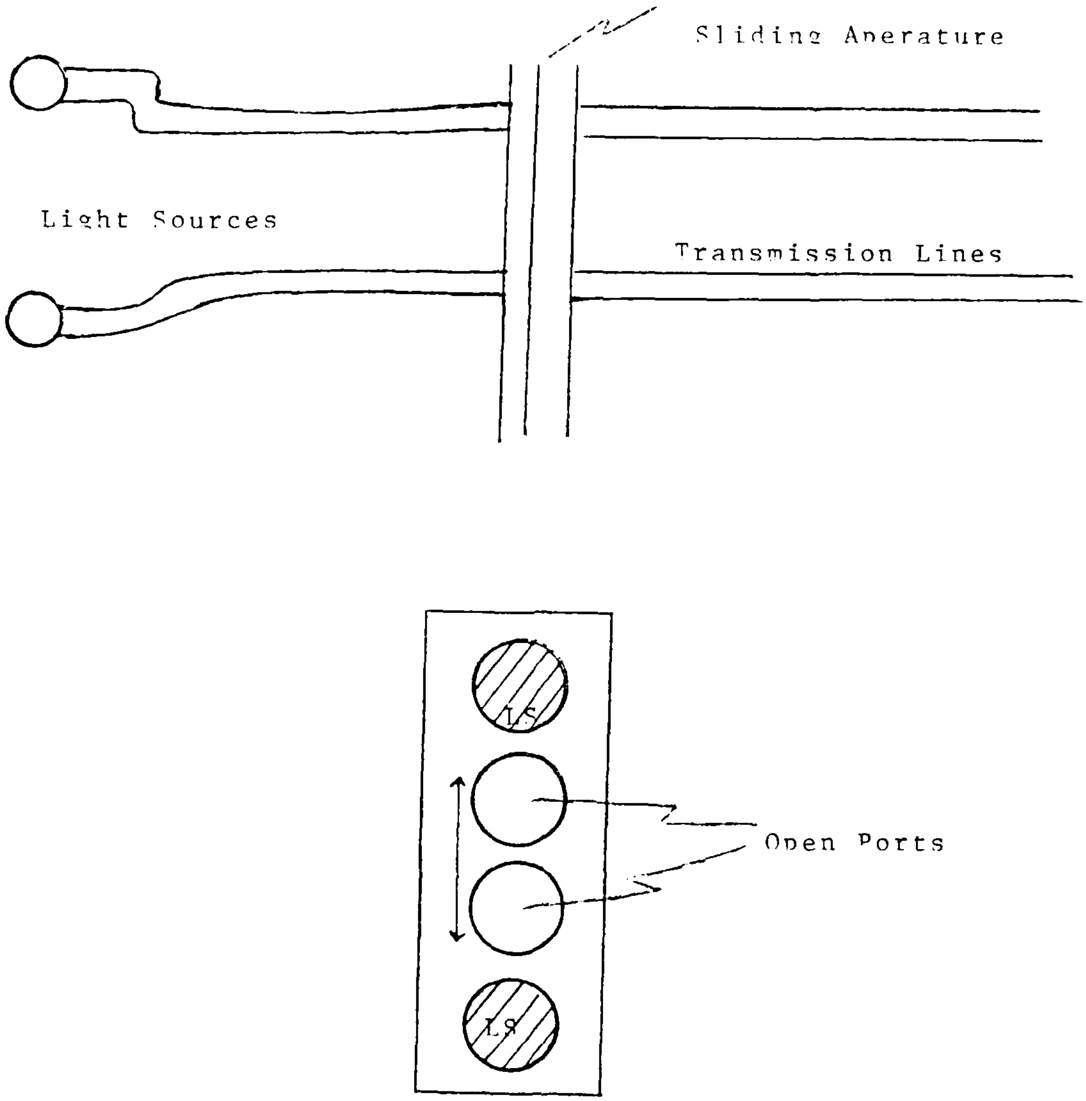

Figure (5) Two transmission line sensor

EMITTERS

The second major component necessary to replace the current collective flight control system is the light source. If a light source is to be used in a fiber optic system, it must meet certain requirements. First, the area of the device that is producing light must be smaller than the core of the fiber in use. Second, if the light emitted is not already in a narrow beam, it must be focused to provide the narrow beam. Third, the light emitted must be stable in amplitude. Finally, depending on the fiber used, the wavelength of the light emitted must be compatible with the fibers attenuation spectrum.[5]

There are two basic light sources now in use on fiber optic systems, light emitting diodes and laser diodes. Light emitting diodes (LED's) make use of light that is emitted upon the recombination of carriers injected into a specified region across a forward biased P-N junction.[6] The light flux from the LED is coupled into the fiber normally by the use of a "well", an etched area in the device that focuses the emitted light.[7] LED's have a nearly linear relationship between the current that is fed into the device and the amount of light flux emitted. This fact contributes to the LED's popularity in analog systems. LED's can produce a broad optical spectrum depending on the materials used. Therefore, if a particular wave length is desired, an LED could quite possibly produce the wavelength desired. The LED is normally used in systems with low data transmission rates (less than 50 megabits/second). The LED, by virtue of its operation, is not very sensitive to temperature variations and aging. The LED is the usual choice for short distance point to point transmission systems that are operating in the short wavelength band.[8]

Laser diodes operate in much the same fashion as an LED. The difference occurs in the emission of the light produced. Laser diodes use a resonant cavity in their structure. This cavity confines some of the light produced by the recombination of the carriers. Because of the confinement some feedback occurs. At a certain point, the light produced will exceed the cavity's ability to confine the light and lasing takes place.[9] Due to this feedback phenomenon, the laser diode must reach a threshold current prior to starting laser action. Recent research has indicated that this threshold current increases with an increase in temperature. Laser diodes are more efficient than LED's at coupling light into a fiber (approximately 10 times). Laser diodes also work at higher bit rates than LED's (approximately 50 mega bits per second).[10]

The light source that is chosen to operate in the fiber optic collective control system will be exposed to many environmental hazards. Helicopters, traditionally, operate with a rotor RPM of 360 revolutions per minute. The rotors, as they make a complete revolution, never have the same angle of attack at any two points of the revolution. This changing at the high RPM causes vibrations within the airframe. Helicopters are required to operate at all temperature extremes, from artic to tropical. Helicopters, traditionally, produce an excessive amount of static electricity which must be shielded against. Combat conditions require the ability to operate on small amounts of current in the event of power failure of the aircraft and immunity to electromagnetic pulses of nuclear weapons.

The fiber optic collective control system will be a short distance point to point system. The data transfer rate need not be very large. The system should be a digital system as this method of operation will help negate the effects of noise produced by the helicopter. By comparing the characteristics of the light sources and the criteria that they must meet in the fiber optic collective control system, it becomes apparent that an LED should be used. The primary characteristics that contribute to this decision are the LED's ability to produce light at lower current levels, its longer life and temperature insensitivity. An LED will provide the necessary bit rate and meets the light producing criteria of the short transmission length system. An LED is most easily adapted to analog systems, but with proper modulation techniques would work well with digital systems.

An LED modulator/driver that would work well under the conditions described above is shown in figure (6). The 24 volt power source is the battery of the aircraft. The battery is linked to the input of a Colpitts oscillator and the collector of a 2N4418 switching transistor. The Colpitts oscillator provides a 250 kilo-hertz, 1 volt peak to peak signal. The LM 308 operational amplifier is used to amplify the oscillator's signal prior to entering the switching circuitry. The diode labeled as 1 in figure (6) represents the LED. Fluctuations in collector current produced by the switching transistor modulates the LED light flux. Figure (7) shows the output of the oscillator verses the current through the LED. Most LEDs turn on between 50- 100 milliamperes.[11] Therefore, in this circuit, the LED is on (emitting light) when the current reaches the threshold level. The LED turns off (emits no light) when the current decreases below the threshold level. We now have pulses of light produced by the switching of the LED which corresponds to digital signals.

For purposes of this thesis, we will use an AlGaAs LED operating at a wavelength of 0.85 micro-meters. The LED has a rise time of 5 nano-seconds and the light emitting surface is less than 75 micro-meters. The LED produces 1 milliwatt of power at 50 milliamperes current. Again, losses will occur when mating the LED to the fiber. As in chapter II, the fiber specified has a numerical aperture of 0.1868 which produces losses of 14.57 dB. These losses can be reduced by using edge emitting diodes rather than surface emitting diodes and by the use of lenses. However, with small numerical aperture fibers, the best we can hope for is a loss of approximately 12dB.[12]

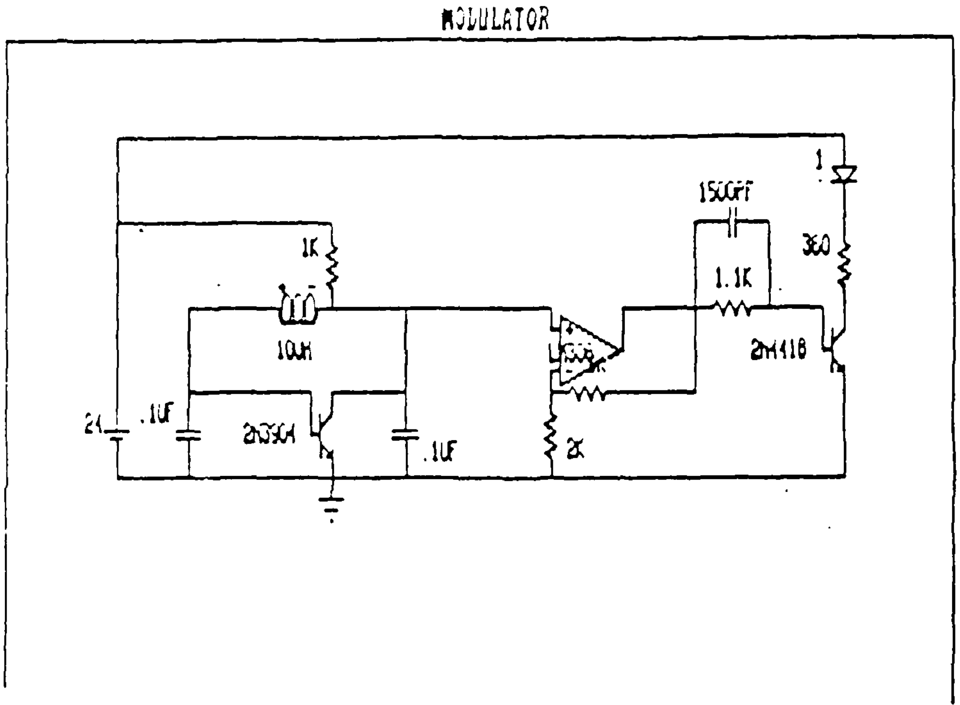

Figure (6) Modulation Circuit

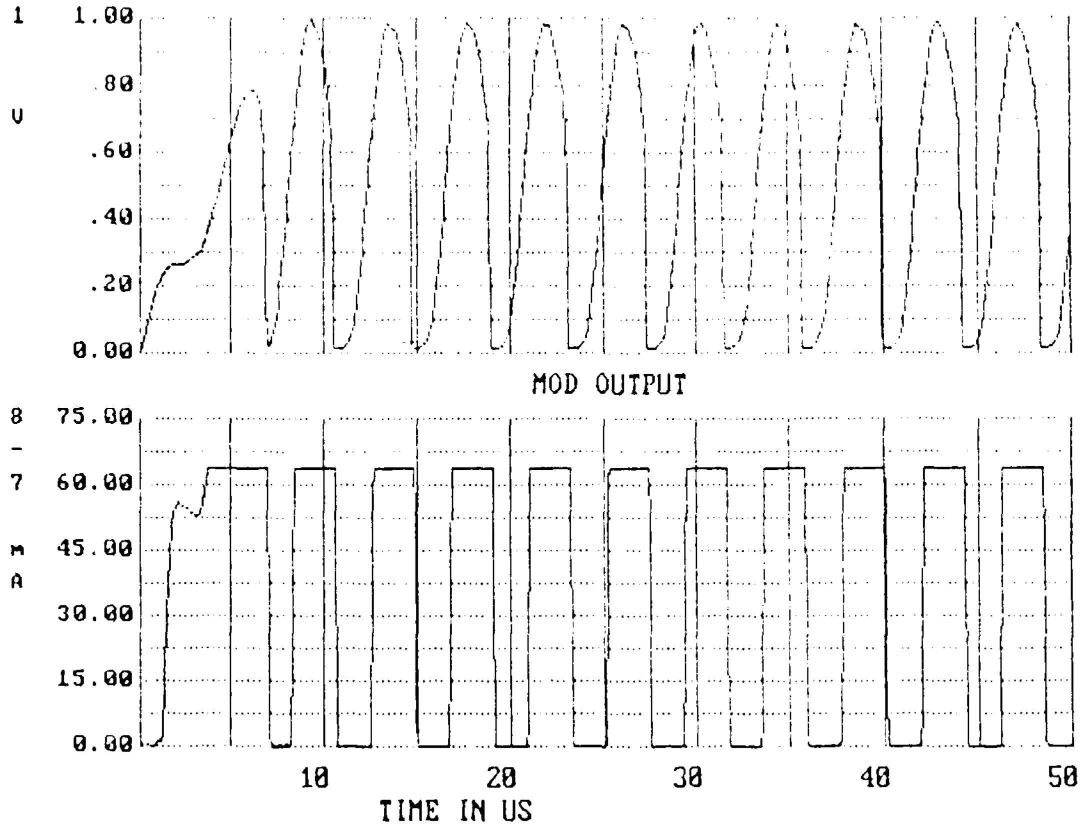

Figure (7) Modulation circuit output

CONNECTORS

Connectors are a vital part of the fiber optic collective control system. The construction of helicopters with firewalls and structural supports make it a reality that components will have to be moved from time to time in order to perform maintenance on other sections of the aircraft. The easiest way to perform this function is with connectors.

There are three problems of alignment of the optical fiber that must be considered when comparing different types of connectors. The three problems are angular tilt of the fiber, end separation, and lateral misalignment of the fiber.[13] Angular tilt (see figure (8)) is a measure of the angle between the ends of two mated fibers. Attenuation values vary depending on the numerical aperture of the fibers involved. Most connector designs keep the amount of angular tilt involved to around 1 degree. This displacement will normally produce on the average of 0.1-0.2 dB Of loss.[14]

End separation is most easily described as a displacement between the fibers in longitudinal distance. See figure (9). Again, the losses due to end separation vary according to the numerical aperture of the fibers involved. Current connectors keep the losses due to end separation to within 0.1-0.3 dB.[15]

Lateral misalignment occurs when the two mated fibers meet or touch but only over part of the fiber face. See figure (10). Lateral misalignment is not necessarily a function of numerical aperture. The losses due to lateral misalignment are normally up to 0.5 to 0.7 dB in current connectors.[16]

There are two basic types of connectors available termed lens coupled and butt coupled. The lens coupled device makes use of a focusing lens between the two fibers. One particular lens coupled device makes use of a double concave lens. See figure (11). In this device the light from the fiber strikes the concave lens on one side. The light travels through the lens to the other side where the concave portion refocuses the light on to the end of the departing fiber. These designs keep total losses to around 2dB and are less susceptible to end separation and lateral alignment losses. However, they are more likely to have losses due to angular misalignment.[17]

The butt coupled device does exactly what its name implies. The device mates the ends of the fibers exactly, butt end to butt end. The device makes use of a channel guiding section for the fiber in order to place the fiber in position to mate. Some techniques include the three rod alignment, a common sleeve, or three molded walls. The device also uses molded a threaded sleeve to hold the fibers together once they are mated.[18,19]

As stated earlier, connectors will play a major role in the fiber optic collective flight control system. When evaluating the connectors to be used we need to consider factors such as ease of connection, reliability, and sustainability after repeated mating and unmating in addition to the losses in power flux. The losses in this system need to be held to a minimum, however, they are not as critical as some of the other factors. This fact is due to the short length of the fiber transmissions system. Ease of connection plays a more important role especially when viewed in conjunction with the repeated connections and disconnections the device will be exposed to. A soldier working on an aircraft is likely to try to force a connection together if the connection offers a lot of resistance or is tedious to accomplish. The forcing of the connection is likely to destroy or deform the fibers involved causing malfunctions in the system.

The lens coupled device has some disadvantages in this system. The delicacy of the lens makes the device more susceptible to vibrations and rough handling than the butt coupled connector. Although, alignment in the lens coupled device is not a factor, the continued mating and unmating that the device will be exposed to along with the weather conditions under which it must operate might cause corrosion or cracking of the lens. Therefore, the butt coupled device is the better choice for the fiber optic collective flight control system.

The cables of the fiber optic collective control system will have to pass through a minimum of two firewalls. Therefore, two connectors will be utilized. In addition to allowing disconnection and removal of the fiber cables, the connectors will protect the fiber cables from abrasion as they pass through the firewalls. The losses due to the connectors are approximately 1.2dB per connector. This value is obtained by taking the maximum normal loss for each of the alignment problems discussed earlier.

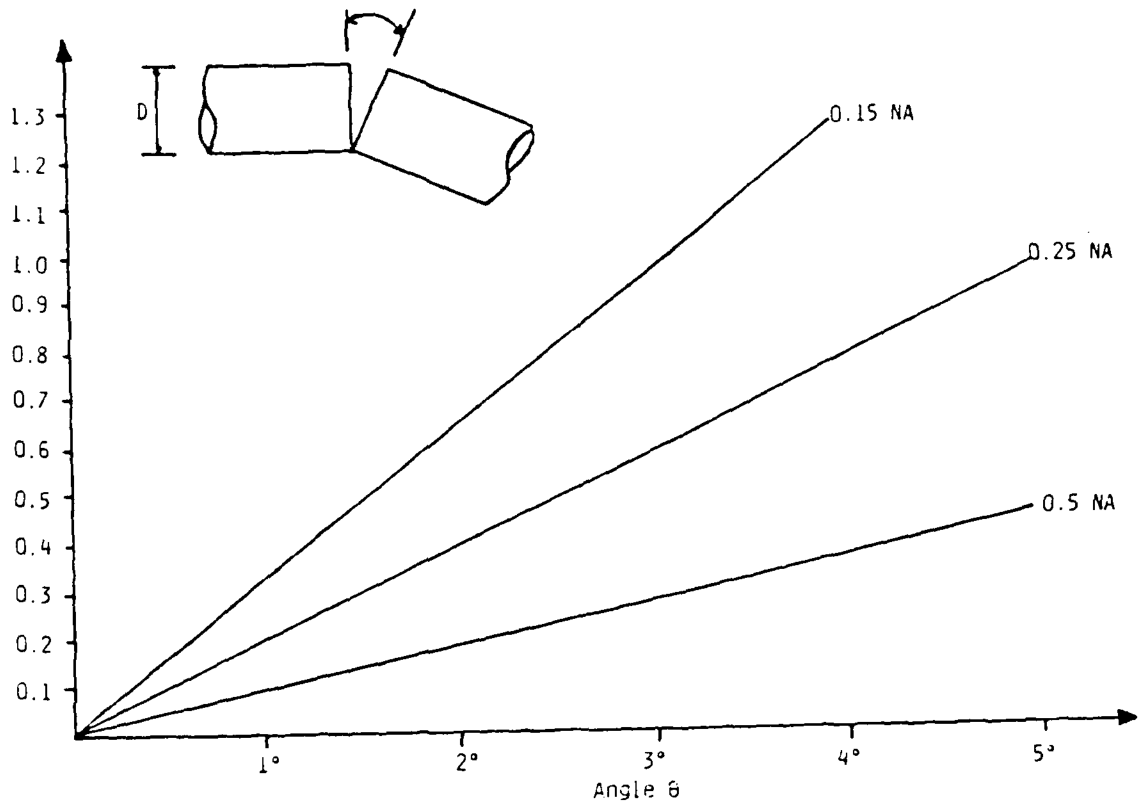

Figure (8) Angular Tilt
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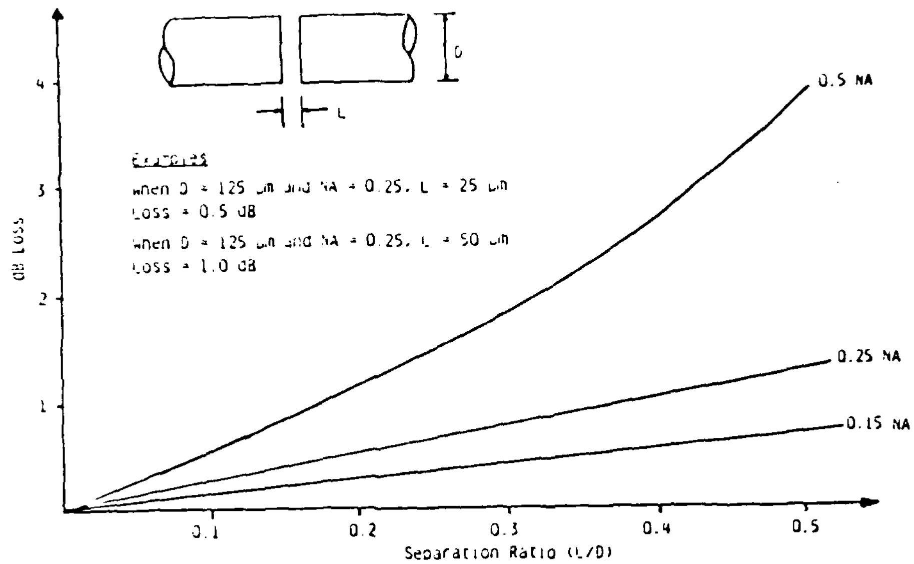

Figure (9) End Separation
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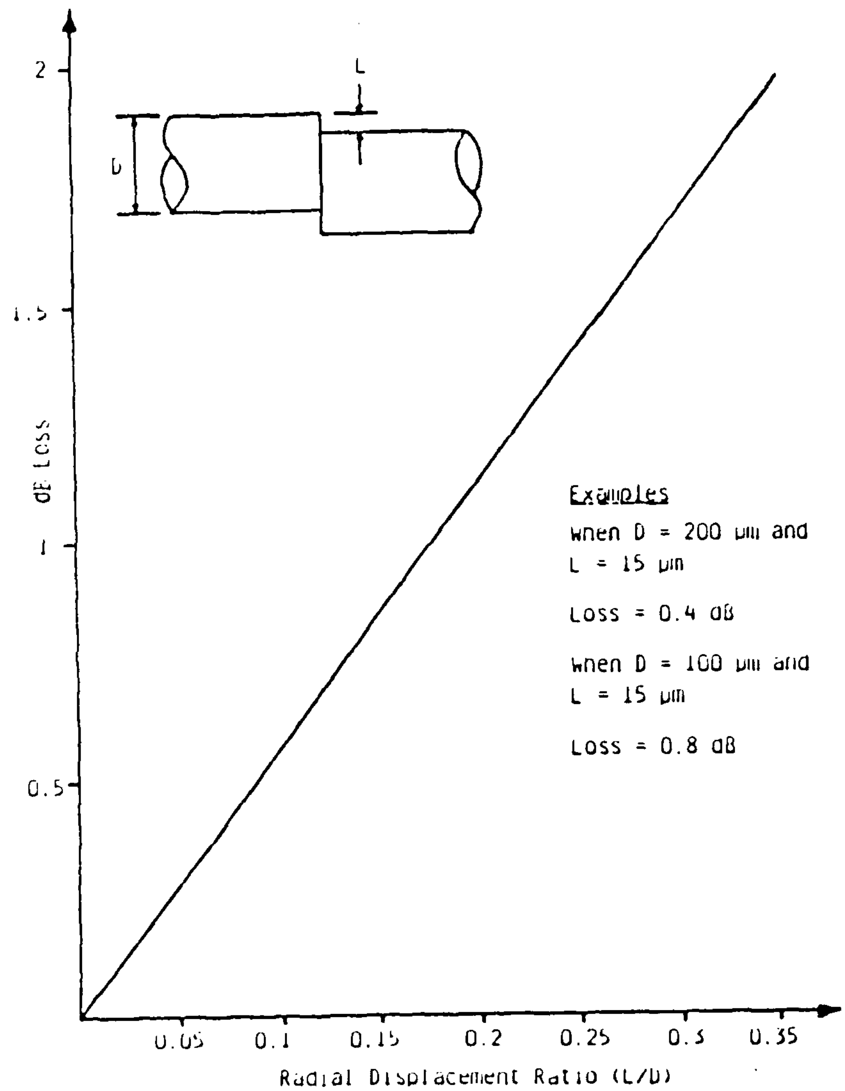

Figure (10) Lateral Misalignment
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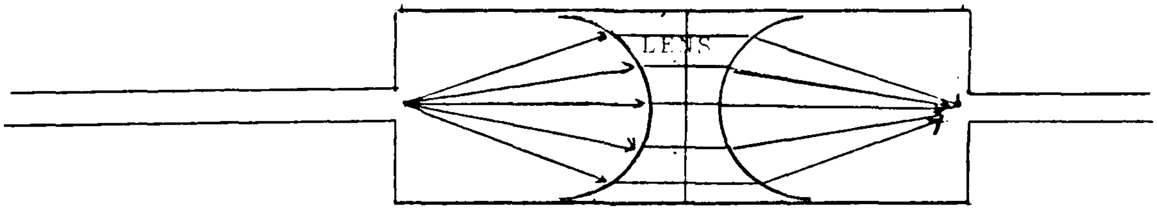

Figure (11) Lens coupled connector

FIBERS AND CABLES

In order to pass the light from the sensor to the receiver, there must be a specially constructed fiber connected between the two points. Currently, two basic materials are used in the construction of these fibers, glass or silica, and plastic. The fibers constructed of plastic are very flexible and inexpensive to manufacture. Plastic fibers can withstand greater stress than glass fibers especially in the bending motion. Plastic fibers also weigh 40% less than glass fibers. However, the plastic fibers have a limited temperature range of operation, between 0 and 70 degrees celsius.[20,21] Because of the temperature restriction, the fiber optic collective control system must utilize glass fibers.

Even though we tend to think of glass as easily broken, glass fibers are known to have a tensile strength as strong as that of stainless steel.[22] Some of the best silica fibers use a core doped with Germania in order to enhance their refractive index. Silica fibers are more transparent at wavelengths greater than 1 micrometer and are very tolerant to changes in temperature.[23]

There are three factors that affect a fibers performance. These three are attenuation, dispersion, and numerical aperture. Attenuation is power or light flux losses that are caused by material absorption, light scattering, fiber imperfections, and sometimes by the cabling method used.[24] Recent studies have found that attenuation in the fiber depend on the wavelength of light transmitted. For a wavelength of 0.85 micrometers, silica fiber typically has an attenuation of 2.5 to 3 dB per kilometer. If the wavelength of the light is increased to 1.3 micrometers, the attenuation drops to 0.3 to 1 dB per kilometer.[25]

Dispersion is a measure of the broadening of a pulse of light as it travels through the fiber. Dispersion is brought about by slightly different wavelengths of light traveling down the fiber at different speeds. Therefore if a pulse of light, approximating a square pulse, is transmitted through a fiber with high dispersion, the output of the fiber may appear as more of a sinusoidal pulse, not recognizable by the receiving circuitry. Dispersion also varies with wavelength. At a wavelength of of 0.85 micrometers, the dispersion is approximately 90 picoseconds per kilometer-nanometer, interpreted as 90 picoseconds of delay per kilometer of fiber per nanometer change in wavelength. At 1.31 micrometer wavelength, the dispersion essentially disappears and then increases at longer wavelengths.[26]

Numerical aperture is a measure of the angular spread of the light that can be accepted and then transmitted by the optical fiber. Numerical aperture is a function of the differences between the refractive indices of the core and cladding. An expression for the relationship is $NA = (n_1^2 - n_2^2)^{1/2}$ where n_1 is refractive index of the core and n_2 the refractive index of the cladding. Therefore, the larger the numerical aperture, the better the fiber in the sense that more light can be accepted and transmitted.[27]

When we consider the fiber, we have to be careful not to confuse the fiber with the cable package. See figure (12). The optical fiber actually consists of the silica or plastic core and the cladding. The remainder of the sections protect the fiber and enhance its handling. These sections constitute the fiber cable. There are two methods of placing the fiber in the cable termed tight package and loose tube construction. See figure (13). In the loose tube construction the fiber is given room to move within the cable. This arrangement enhances the bending ability of the fiber eliminating the microbending losses, however it is susceptible to vibration and shock as are all fibers. The tight package construction mates the fiber to the cable sections. This arrangement protects the fiber better but is not as well suited to bending.[28]

For application to the fiber optic collective control system, we must again look at the requirements.

The system is short in length which allows some freedom with respect to attenuation. The actual fiber length necessary to complete the connection between the sensor and the photodetector is at most 5 meters. The temperature extremes that the system will be exposed to dictate that a silica fiber be used. We also have some freedom with the diameter of the fiber as the system requires only two fibers be passed through the cable. An all silica fiber, manufactured for military use, has a large diameter (greater than 200 micrometers) and is constructed using step index profiles.[29] Step index refers to the construction of the fiber with regard to the refractive index of the core and cladding. Specifically, the core has a refractive index of n_1 and the cladding a refractive index of n_2 (n_1 greater than n_2). The interface between the core and cladding in a step index fiber is abrupt.

The loose tube cable construction is the best cable choice for this system. The loose tube cable allows for some bending of the cable which will be required in the system. The open section of the cable can be filled with a foam to enhance its protection against moisture. The loose tube construction also allows for expansion and contraction due to changes in temperature.[30] In chapter II, a two fiber sensor was chosen. Both fibers can be placed in the same cable under loose tube construction as shown in figure (14).

Using the fiber specified in chapter III (silica core, 2% doped silica florine cladding) we see that the numerical aperture of the fiber is 0.1868. Losses due to dispersion in this fiber are approximately 40 nanoseconds per kilometer. The distance in this system is 5 meters which yields a dispersion of 0.2 nanoseconds,a figure that can be disregarded. Losses due to attenuation in the specified fiber approach 3dB per kilometer yielding an attenuation loss in this system of 0.015 dB.

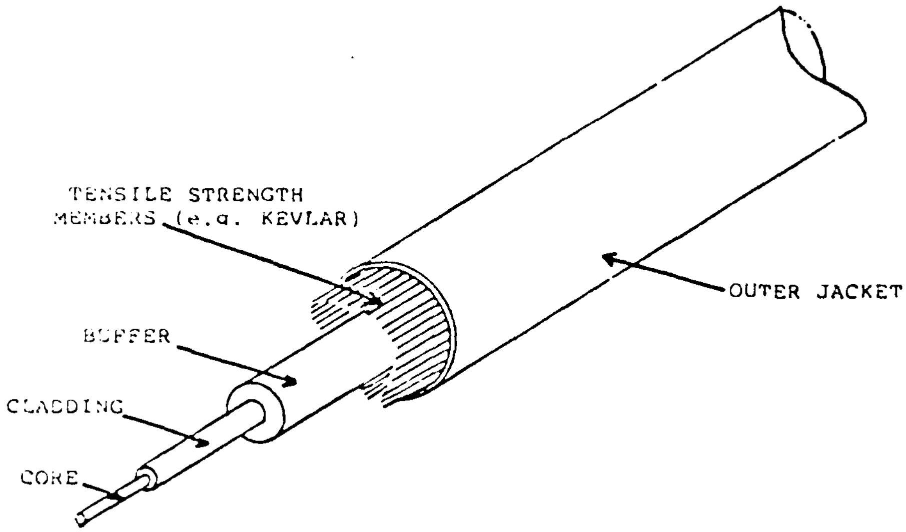

Figure (12) Fiber Assembly
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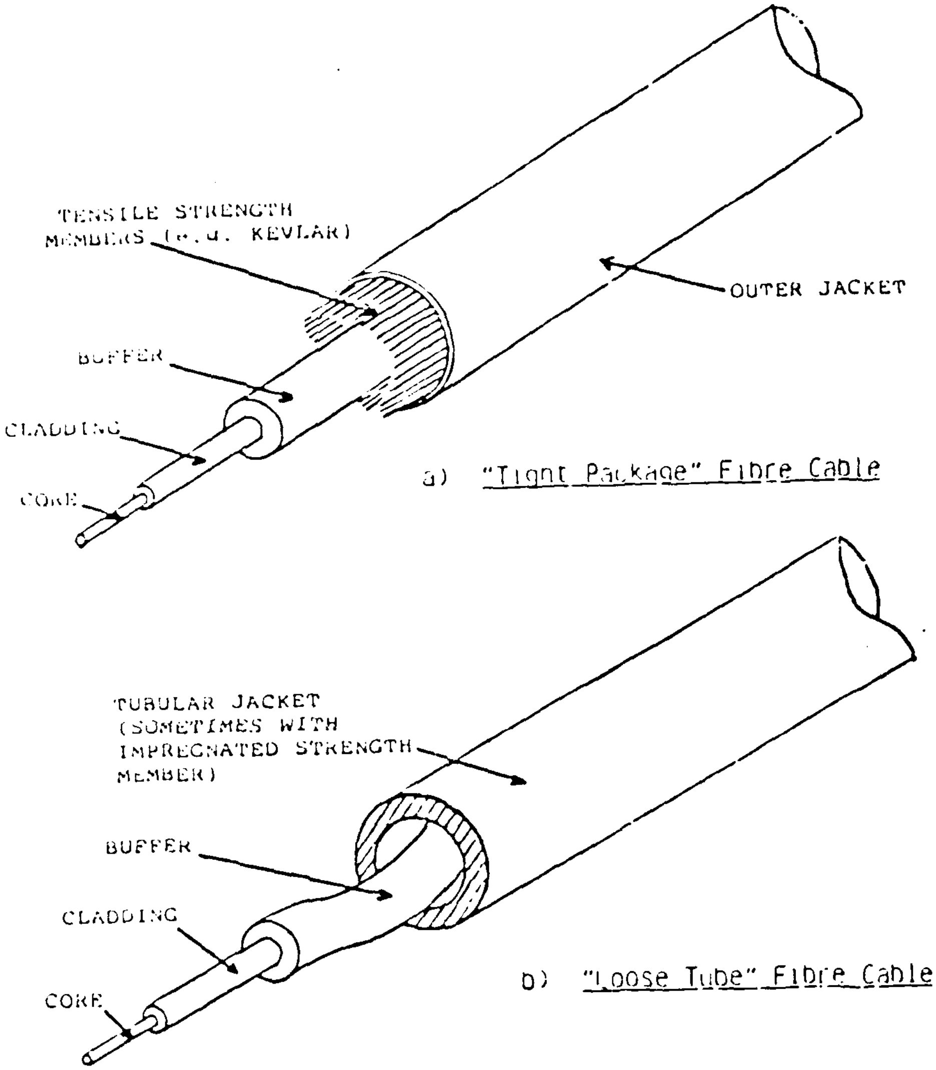

a) "Tight Package" Fibre Cable

b) "Loose Tube" Fibre Cable

Figure (13) Tight Package vs Loose Tube
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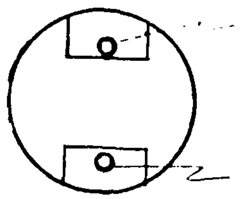

Figure (14) Two fiber loose tube

RECEIVERS

Once the light flux has reached the end of the fiber at its destination, it must be converted back to an electrical signal for use by the collective control system. The first link in this process is the photodetector. The photodetector in this system must meet several stringent requirements. The photodetector must have a high quantum efficiency, high responsitivity and an active area of sufficient size to allow a maximum of emitted light from the fiber to land on the active area. High quantum efficiency implies that the ratio of generated electrons to incoming photons of light is large. Responsitivity is a measure of the current developed per unit optical power incident upon the detecting surface. Responsitivity is usually measured in amperes per watt.[31]

The two devices that best meet the criteria are PIN photodiodes and avalanche photodiodes. PIN photodiodes are so named due to their structure. There is a large intrinsic layer between a layer of P type material and a layer of N type material. Hence the designation PIN or positive-intrinsic-negative. The PIN photodiode is very sensitive to light and reproduces the electrical signal well. However, due to its structure, it produces no internal gain and is therefore used in short length systems where the intensity of light flux in the fiber is not a problem. The PIN is tolerant to temperature changes and is lower in price than the avalanche photodiode.[32]

Avalanche photodiodes or APDs use the same principle of operation as PIN photodiodes but their structure is arranged such that emitted electrons are allowed to strike other electrons creating a multiplying effect. APDs therefore produce an internal gain. Due to this characteristic, APDs are commonly used in long distance systems where the intensity of light flux emitting from the fiber may be very low. APDs are more sensitive to changes in temperature than the PIN photodiode.[33]

The fiber optic collective control system is a short distance system as discussed before. The relative merits of each of the types of photodetectors indicate that due to its better temperature tolerance the PIN photodiode should be used in the system. Specifically, the system will use a silicon PIN photodiode with a rise time of 0.5 nanoseconds and a responsivity of 0.5 amperes per watt. Each fiber in the cable will terminate with a PIN as specified.

Summing the losses of light flux in the system thus far, we find that the total loss comes to 28.9 dB.. This total is from the 12 dB loss due to coupling the fiber to the LED, the 14.5 dB loss at the displacement sensor and a 2.4 dB loss due to connectors on the cable. Using the decibel relation ($dB = 10 \log_{10} P_{out} / P_{in}$), we find that the system has an efficiency of 0.128%.[34] Therefore, with 1 milliwatt of power transmitted, the PIN will receive 0.128 milliwatts of power. The response of the photodiode yields a current of 0.064 milliamperes.

A possible receiving circuit is shown in figure (15) . A voltage dependent current source was used to model the output of the photodiode. The 2.3 picofarad parallel capacitance simulates the capacitance of the photodiode. LM 308 operational amplifiers were utilized to provide the necessary gain and to filter out the possible noise interference due to other electrical devices in the helicopter. The LM 308 was also chosen for its high slew rate. A worst case analysis of the receiver circuit appears in figure 16. The model parameters of the LM 308 were allowed to vary as much as 50%. As is seen in figure (16), under the worst conditions of parameter variations, the output of the circuit remains better than 3 volts peak. The receiver model was also tested by the computer to operate at 70 degrees celsius producing no change in its output. The signal to noise ratio of this receiver was computed using the combined effects of thermal noise and shot noise. The signal to noise ratio was approximately 60dB.

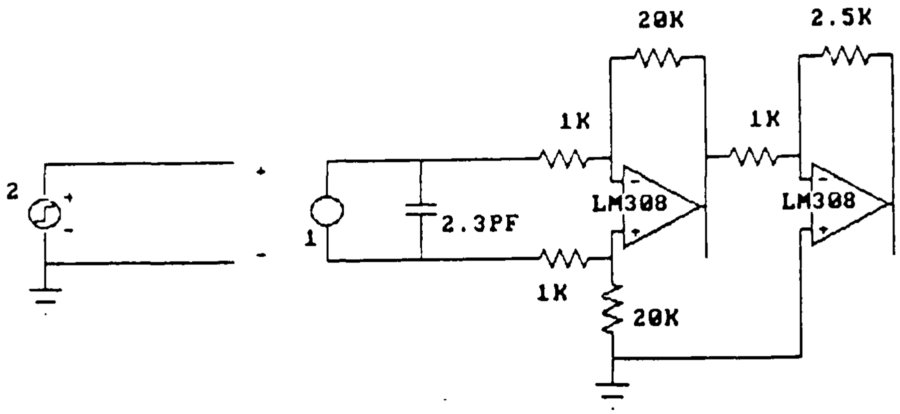

Figure (15) Receiving Circuit

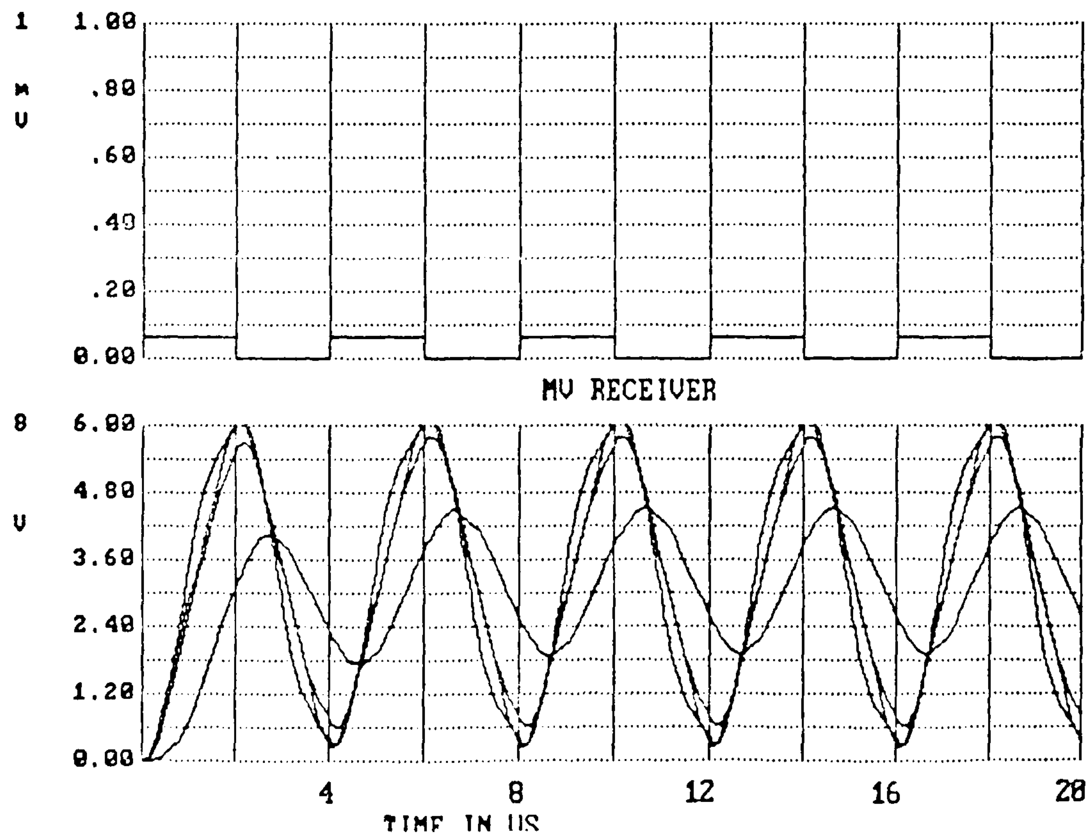

Figure (16) Receiving Circuit Output

HYDRAULIC INTERFACE

With the required signal at the receiver, the task now becomes changing the electrical signal into a mechanical input. In the current collective control system, hydraulics are used to effect the changes to the rotor blades. Hydraulics were chosen due to their damping properties and their ability to generate large amounts of pressure. The requirements not having changed, hydraulics should be used in the fiber optic system also.

Presently, there are three methods of controlling hydraulics with electrical signals: solenoid valves, servovalves, and proportional control valves. Solenoid valves are essentially on - off valves. They are easily triggered by electrical pulses . Servo-valves and proportional control valves are closely related. The primary difference between the two valves is servo-valves are normally used in closed loop feedback systems while proportional control valves are used in open loop feedback systems. Proportional control valves are not as responsive as servo-valves. However, the step response of a proportional control valve is 50 milliseconds to 0.5 seconds. The step response is the speed at which the valve spool can move from one position to another. Proportional control valves are interchangeable as opposed to servo-valves whose parts are machined for that one valve.

Additionally, proportional control valves are more tolerant to contaminants in the hydraulic system than servo-valves. As a result, proportional control valves are the choice for controlling the hydraulics of the fiber optic collective control system.[35]

Proportional control valves are simple in construction and function. See figure (17). Their construction is broken down into two sections, an electromechanical section and a hydraulic section.[36] As seen in figure (17), the electromechanical section consists of a permanent magnet, an electrical coil and an armature. Changes in the magnetic flux brought on by the time varying input electric current causes th armature to move thereby opening and closing a poppet valve. The hydraulic section consists of an inlet port for control hydraulic pressure, an outlet port for supply pressure and a venting port. When the poppet is closed, pressure is supplied to the system. Accordingly, when the poppet is opened pressure is vented from the system.

One of the major advantages of proportional control valves is that they may be modeled to the system. The poppet can be structured such that it is normally open when a voltage is applied or it may be structured in the opposite manner. Another advantage is that the electronics controlling the hydraulics can be placed away from the hydraulic cylinders themselves in order to protect the electronics from heat and vibration.[37] The hydraulic control system proposed for use in the fiber optic collective control system is depicted in figure (18). The hydraulic system makes use of two proportional control valves connected to a common supply valve. The supply valve is connected to both sides of a hydraulic arm. In order for the arm to move, the pressure on the arm must be relieved in the direction of movement and pressure increased on the side of the arm opposite movement. Both proportional control valves are normally closed and are set to open or vent when voltage is applied to them. Therefore, at rest, both poppet valves are closed and equal pressure is applied to each side of the hydraulic arm. In order to extend the arm, the proportional control valve on the right receives voltage. It then opens the poppet and vents the upper side of the hydraulic arm. At the same time, The proportional control valve on the left remains closed and allows fluid to flow into the cylinder to maintain constant pressure. When the up signal stops, the hydraulic system equalizes pressure to hold the arm in its new position. For downward movement, the same process occurs with the proportional control valve on the left receiving the signal to open.[38] As seen in the diagram, the proportional control valves can be located away from the hydraulic arm depending on the length of hydraulic hose connected to the supply valve. In addition to being designed to be normally closed, the proportional control valves will be designed to function with 3 volts input. As seen in the output of the receiver circuit, this design parameter would provide a margin of safety to the fiber optic collective control system.

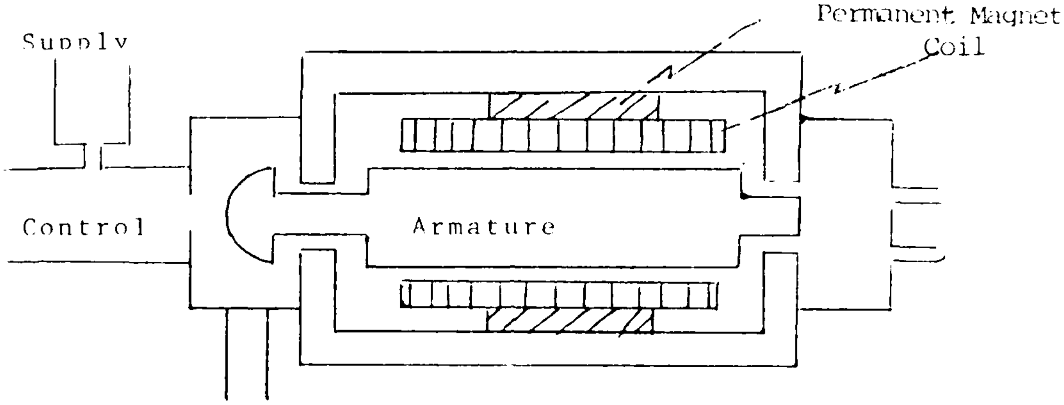

Figure (17) Proportional Control Valve

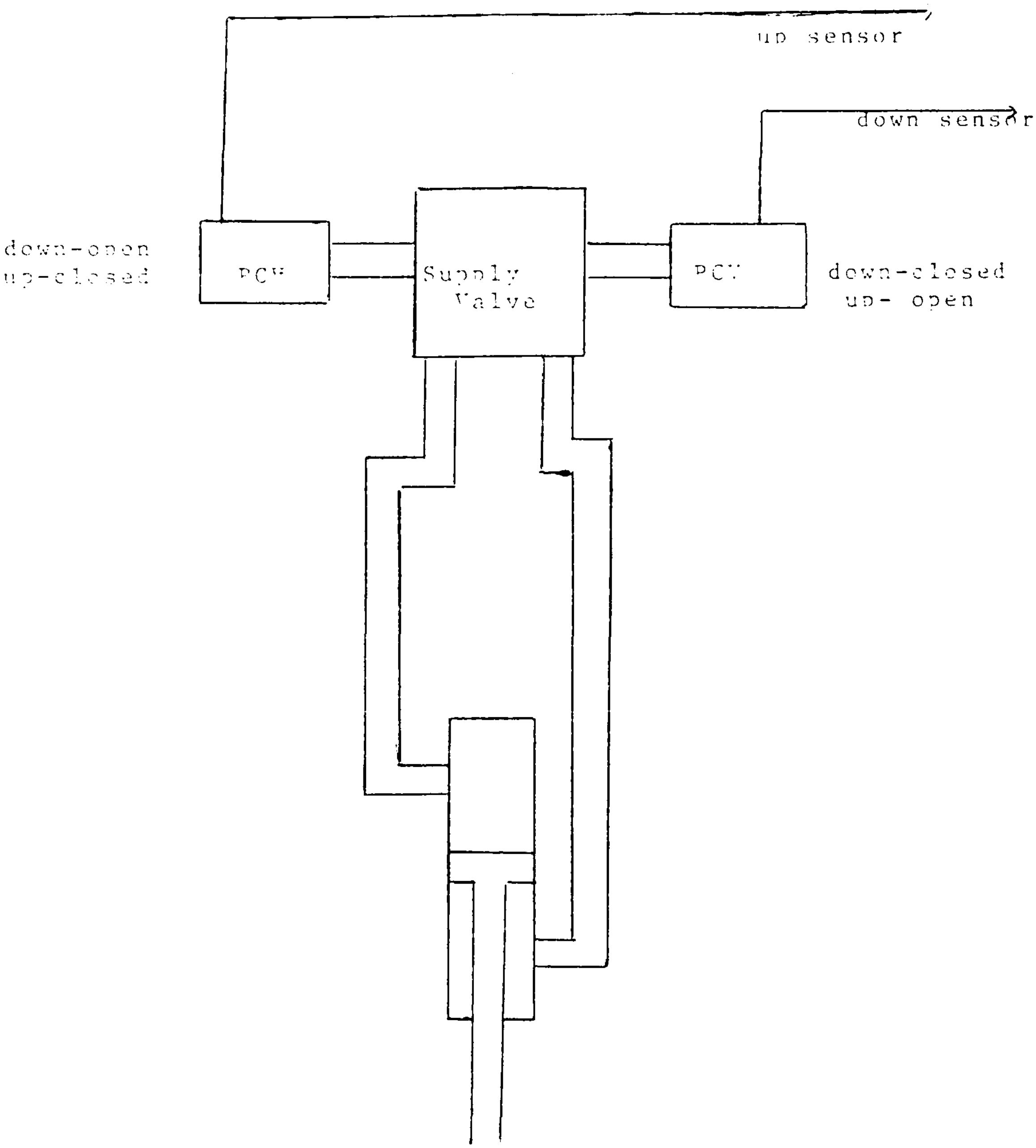

Figure (18) Hydraulic Control System

SUMMARY

A block diagram of the fiber optic collective control system appears in figure (19). The system demonstrates the feasibility and advantages of replacing the present collective flight control system with fiber optics. The fiber optic system is capable of performing under all combinations of environmental factors to which the helicopter would be exposed. The fiber optic system eliminates the adjustment requirements of the present system. Additionally, since the fiber optic system is so lightweight,three lines could be run that carry the same signals while still providing an advantage in weight and greatly expanding survivability of the aircraft. The change in the collective control lever described provides additional room in the cockpit of the aircraft.

There are other advantages to the fiber optic system that were not brought out in this thesis. Since the collective control system can be modified to a fiber optic system the cyclic system and the antitorque system can also be modified. This modification increases the advantage of weight and cockpit reduction. The fiber optic system is immune to electromagnetic pulses which is necessary in a nuclear environment. Also, the flight controls can now be interfaced with a computer that could provide automatic flight controls for the helicopter.

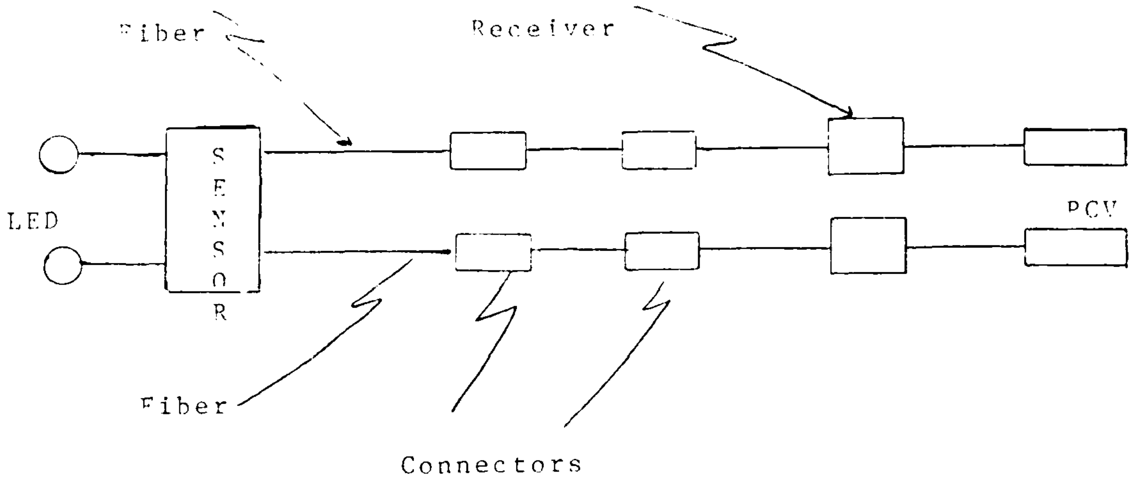

Figure (19) Block Diagram of Control System

References

1. Operator's Manual, TM 55-1520-236-10, 11 January 1980, page 2-21, paragraph 2-30.

2. AH-1S (FM) Flight Controls and Hydraulics, Student Handout, July 1981, page 24.

3. David A Krohn, "Inside Fiber Optic Sensors," Chilton's Instrumentation and Control Systems, 56, No. 9, Sept. 1983, p. 57.

4. D. Wobschall and S. Hejazi, "Aperture Intensity Ratio Fiber Optic Displacement Sensor", Review of Scientific Instruments, 58, August 1987, p. 1543-1544.

5. Data Transmission Using Fibre Optics: A Review of Production Techniques. (Westland Helicopters Limited, Yeovil, England, 1982), Vol. II, p. 23.

6. D.J. Channin, "Emitters for Fiber Optic Communications", Laser Focus Fiberoptic Technology, 18, No. 11, November 1982, p. 105.

7. Channin, p. 106.

8. Channin, p. 109.

9. Channin, p. 106.

10. Channin, p. 106.

11. Joseph C. Palais, Fiber Optic Communications, (Prentice Hall, 1988) pp. 130.

12. Palais, pp. 187.

13. R. C. Cunningham, "Fiber Optic Connectors - Better than Ever", Electro-Optics, 15, No. 8, August 1983, p. 35.

14. Cunningham, p. 36.

15. Cunningham, p. 36.

16. Cunningham, p. 36.

17. Cunningham, p. 37.

18. Cunningham, p. 36.

19. Data Transmission Using Fibre Optics: A Review of Production Techniques, (Westland Helicopters Limited, Yeovil, England, 1982), Vol. II, p. 16.

20. Edward A. Lacy, Fiber Optics, (Prentice Hall, 1987) pp. 70.

21. Data Transmission Using Fibre Optics: A Review of Production Techniques. (Westland Helicopters Limited, Yeovil, England, 1982), Vol. II, p. 12.

22. Lacy, pp. 71.

23. Felix P. Kapron, "Fiber-optic System Tradeoffs", IEEE Spectrum, 22, No. 3, March 1985, p. 68-75.

24. Data Transmission Using Fibre Optics: A Review of Production Techniques. (Westland Helicopters Limited, Yeovil, England, 1982), Vol. I, p. 6.

25. Kapron, p. 71.

26. Kapron, p. 71

27. Data Transmission Using Fibre Optics: A Review of Production Techniques. (Westland Helicopters Limited, Yeovil, England, 1982), Vol. I, p. 6.

28. Palais, pp. 119.

29. Data Transmission Using Fiber Optics: A Reivew of Productions Techniques. (Westland Helicopters Limited, Yeovil, England, 1982), Vol. II, p. 12.

30. Palais, pp. 119.

31.Data Transmission Using Fibre Optics: A Review of Productions Techniques. (Westland Helicopters Limited, Yeovil, England, 1982), Vol. II, p. 23.

32.Data Transmission Using Fibre Optics: A Review of Productions Techniques. (Westland Helicopters Limited, Yeovil, England, 1982), Vol. II, p. 26.

33. Kapron, pp. 68-75.

34. Palais, p. 13.

35. R. W. Henke, "Electrohydraulic Proportional Control Values", Hydraulics and Pneumatics, 38, April 1985, p. HP20-32.

36. Henke, p. HP20-32.

37. Henke, p. HP20-32.

38. Henke, p. HP20-32.

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Feb. 22, 1988

Major E. Golson
902 S. 24th Street
Kingsville, TX 78362

Our Ref: ltr 005/88 MKTG1

Dear Major Golson

FIBER OPTIC PRODUCTION STUDY

Thank you for your letter of 31 January 1987 - we have no objections to you making use of some of the illustration providing you forward a list of the illustrations including the volume number and figure number. I apologize for the delay but I had to get clearance from the UK.

We are pleased you found the material we supplied useful.

Yours sincerely,

John Leverton.

Dr. John W. Leverton
Manager, Operation Development
& Environmental Projects

JWL/jmm

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[illegible]ville, [illegible]
78363

Dr. John W. Leverton
1735 Jefferson Davis Highway
Suite 605
Arlington, Virginia 22202

Reference: Fiber Optic Production Study

Dear Sir:

Thank you for your letter of 22 Feburary 1986. I appreciate the time and trouble you have gone to on my behalf.

Listed below are the illustrations I intend to use in my thesis on Fiber Optic Collective Flight Controls for Helicopters.

Figure #	Volume	Illustration name
8	2	Angular Tilt
7	2	End Separation
6	2	Lateral Misalignment
5a	2	Fiber Assembly
5b	2	Tight Package/ Loose Tube

These illustrations were very helpful in explaining the loses in fiber optic connectors. Proper acknowledgement will be utilized in the production and presentation of the thesis.

Thank you again for your outstanding support.

Sincerely,

Ellis W. Golson
Maj USA

VITA

Major Ellis Wayne Golson is a 1976 graduate of the United States Military Academy at West Point, New York. His undergraduate degree is a Bachelor of Science in general studies. Upon graduation, he served a tour of duty in West Germany as a leiutenant of armor. While there he was assigned as the commander of Combat Support Company, 4th Battalion, 69th Armor. He next attended the United States Army Rotary Wing Flight School at Fort Rucker, Alabama, receiving qualification in UH-1, AH-1, and OH-58 helicopters. Upon completion of training, Major Golson was assigned to the 1st Squadron, 9th Cavalry, Fort Hood, Texas where he accrued 700 hours of flight time and commanded C Troop of the squadron.

Major Golson may be reached at his permanent mailing address; 105 Chapman Street, Evergreen, Alabama, 36401.

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